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EXPERIMENTAL INVESTIGATION OF THE EFFECT OF TURNING CUTTING PARAMETERS ON SURFACE ROUGHNESS AND MATERIAL'S MICROSTRUCTURE AS A FACTOR OF TURNING SPEED VERSUS FEED RATE

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Original Article

ABSTRACT

Surface finish in turning can be influenced by a number of factors such as feed rate, work material characteristics, work hardness, cutting speed, depth of cut, cutting tool characteristics and use of cutting fluids. In this study, experimental tests using a lathe CNC machine were conducted in order to investigate the effects of the cutting speed and feed rate, workpiece hardness and depth of cut on metals surface roughness and microstructure in the hard turning, using as a factor the ratio of turning speed versus feed rate. The machining experiments were conducted on three of the widely used material such as AISI-SAE 304 stainless steel, RSt 37-2 construction steel and UNS C38000 brass.

In order to analyze the effect of the cutting parameters on the surface, two characterization techniques were employed, namely profilometry and microscopy. The topological structure and roughness of the surface were measured using an optical profilometer and the data obtained was analyzed using dedicated commercial software (Visio Software). Furthermore, the detailed microstructure was examined by a field emission scanning electron microscope (SEM).

KEYWORDS: Surface Roughness; Turning; Machining; Microstructural Alterations & Cutting Parameters

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1. INTRODUCTION

Metal cutting is one of the most significant manufacturing processes in material removal. Turning is one of the primary operations in most of the production processes in the industry and for this reason, the surface finish of turned components has a big influence on the quality and the use of the product.

Surface properties such as roughness and microstructure are critical to the functionality of the machined components. Thus, the surface finish has been one of the most important considerations to ensure the product is reliable and with accurate metal parts because it can influence several attributes of a metal part, such as friction, mating characteristics, fatigue, heat transfer, etc.

Surface finish can be influenced by a number of factors such as feed rate, work material characteristics, work hardness, cutting speed, depth of cut, cutting tool characteristics and use of cutting fluids etc. Furthermore, the vast amount of the machining influence parameters can be tuned accordingly to improve the machining performance, which is crucial to the cost and the production time of the machined components as well as the quality

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of the products.

For the reasons mentioned above, the optimization of the cutting process is one of the most important issues in manufacturing. Optimization of machining parameters not only not only improves the economics of precision machining but also the product quality to a great extent.

In the literature, a considerable number of studies investigate the effects of cutting parameters. In [1]-[4] a review of surface integrity in machining, have been presented for various metal alloys. In studies [5]-[12] the effects of several factors on surface roughness have been investigated, such fas, cutting fluids and cooling techniques, cutting force, cutting speed and depth and tool shape. Additionally, in the refs [13]-[18] investigations on the optimization of machining parameters for surface roughness on turning, using mathematical algorithmic and models, have been presented.

This study intends to investigate the effect of the machining parameters in the hard turning, as a factor of turning speed versus feed rate, on metals surface roughness and microstructure.

2 EXPERIMENTAL PROCEDURES

2.1 Turning Conditions

The aim of the experiments was to analyze the effects of cutting parameters on surface roughness during the hard turning of the commonly used materials such as AISI-SAE 304 stainless steel, RSt 37-2 construction steel and UNS C38000 brass. Specimens in cylindrical shape were used with 300 mm long and 16 mm diameter (Figure 1).

Figure 1: Experimental Specimens.

A C.N.C. Haas SL 20 lathe machine was used for the turning, with Tungaloy AH630 TNMG160408-SM carbide cutting tool and Houghton International Hocut 795 cutting fluid.

The experimental tests were conducted using different values of cutting speed and feed rate, in order to investigate the increment of the ratio of turning speed versus feed rate.

The values of the turning parameters used and the definition of each test case for the investigated materials are presented in the following Tables 1 and 2.

Table 1: Turning Parameters for AISI-SAE 304

AISI-SAE 304	Turning Parameters									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Cutting speed V_c (m/min)	150	154	158	162	166	170	174	178	182	186
Turning speed $n=(1000*V_c)/(\pi*d)$ (rev/min)	2986	3065	3145	3225	3304	3384	3463	3543	3623	3702
Feed rate f (mm/min)	508	490	472	451	430	406	381	354	326	296
Factor F = n/f	5,9	6,3	6,7	7,1	7,7	8,3	9,1	10,0	11,1	12,5

Table 2: Turning Parameters for RSt 37-2 and UNS C38000

RSt 37-2 UNS C38000	Turning Parameters									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Cutting speed V_c (m/min)	160	164	168	172	176	180	184	188	192	196
Turning speed $n=(1000*V_c)/(\pi*d)$ (rev/min)	3185	3264	3344	3424	3503	3583	3662	3742	3822	3901
Feed rate f (mm/min)	541	522	502	479	455	430	403	374	344	312
Factor F = n/f	5,9	6,3	6,7	7,1	7,7	8,3	9,1	10,0	11,1	12,5

2.2 Surface Roughness Measurements

Surface roughness measurements were carried out with a WYKO NT1100 white light profilometer (Bruker AXS) using the Vision supporting software. Surface roughness was calculated before and after removing the curvature by using the Bruker Vision software.

Microscopy images were obtained by Field Emission Scanning Electron Microscopy (FE−SEM, FEI InspectTM F50), using the SE detector. The signal by the backscattered electrons was collected by the SE detector and has been converted to a signal that is sent to a computer for further analysis. The images were obtained, using magnifications ranging from 1k to 30k for each sample.

The samples were deposited on carbon tape in order to provide a conductive path.

3. RESULTS AND DISCUSSION

In each specimen surface, the magnitude of the roughness was measured by the surface profilometer and the following parameters were calculated in the investigation:

- The mean measured height taken within the sampling area in respect to the reference mean surface, about which the topographic deviations are measured (surface roughness absolute average, R_a, in μm).
- The vertical distance between the highest and the lowest points of the surface and the mean line within the evaluation area (maximum height of the profile, R_t, in μm).
- The root mean square average measured height taken within the sampling area in respect to the reference mean surface about which the topographic deviations are measured (root mean square deviation, R_q, in μm) and
- The average of successive values of the vertical distance between the highest and the lowest points of the surface and the mean line within the evaluation area (average roughness R_z, in μm).

Additionally, Bruker Vision software was used to analyze and present the results obtained by the profile meter.

In Figure 2, the fluctuation of the roughness is depicted in a closed rectangular frame, which is a 2D photo of the surface. The points of the surface are represented by parallel lines of different colors within a specific color spectrum. The peaks of the surface are symbolized by warmer colors, while the valleys by colder. The black areas symbolize the points of the surface whose roughness could not be measured due to various factors (light scattering, etc.) and the specimen's cylindrical shape.

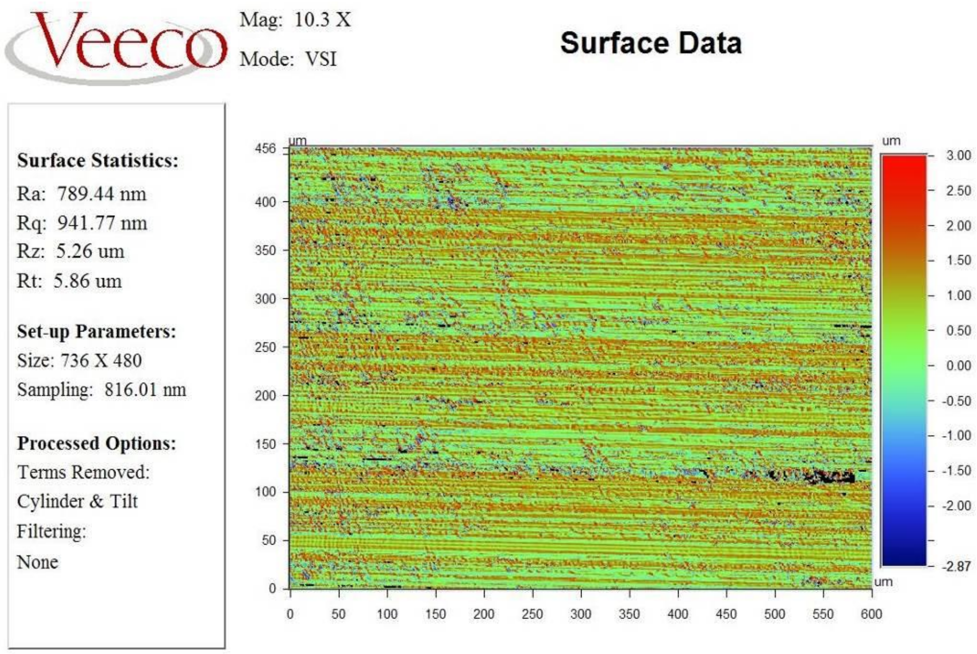


Figure 2: Contour Plot Representation of Surface Roughness.

Figure 3 shows the values of the roughness parameters for a specific point of origin of the surface, which is defined within the area where the Contour plot is displayed. There are two diagrams, one for the profile on the X-axis and one for the profile on the Y-axis. For each point selected, an average of the parameter values is obtained for all points

perpendicular to the axes of the lines passing through the selected point. For the repeatability of the measurements, the measurements were recorded for two different points of the scanned area.

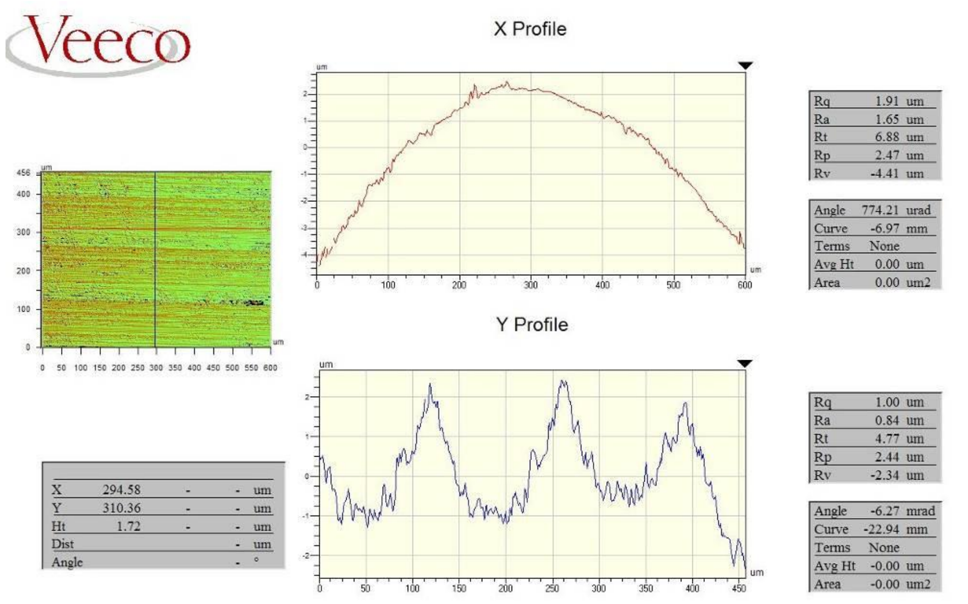


Figure 3: Representation of 2d Analysis of Surface Roughness.

In the 3D interactive plot (Figure 4) a three-dimensional display of surface irregularities is presented.

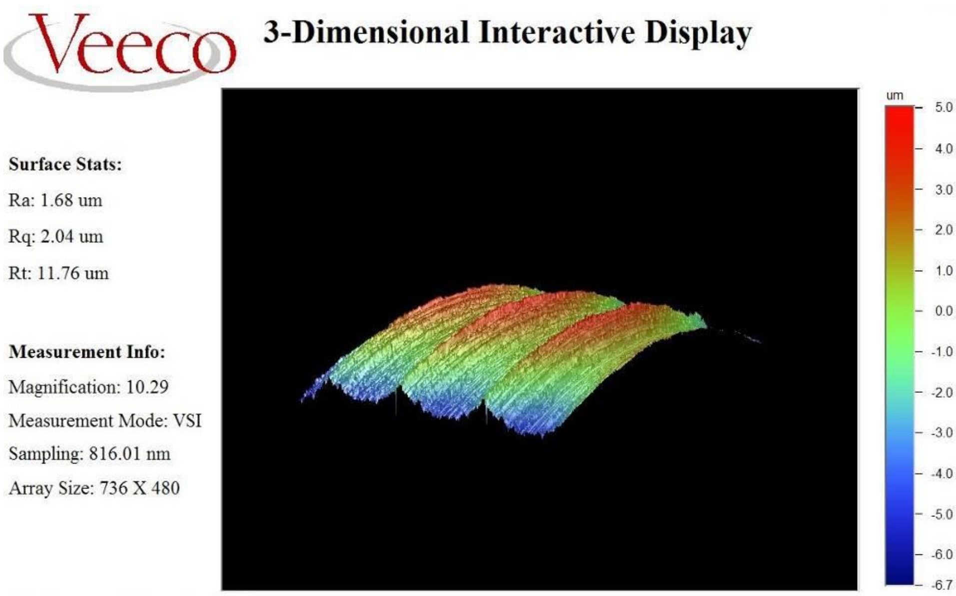


Figure 4. 3D Interactive Plot Representation of Surface Roughness.

In 3D plot, the variations shown in the 3D interactive plot are enclosed by a frame with sides spaced at equal intervals, presented a spatial perspective of the surface (Figure 5).

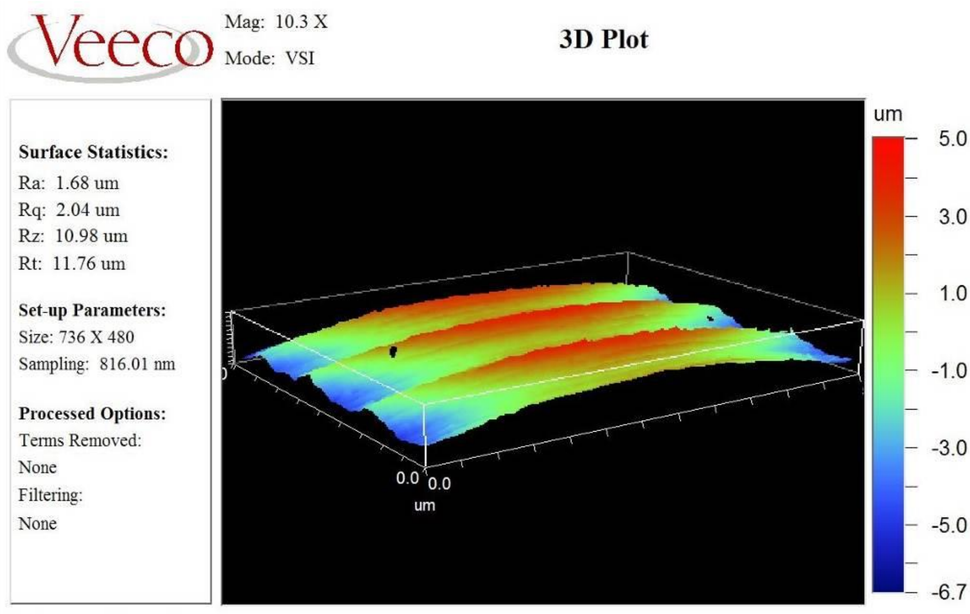


Figure 5: 3D Plot Representation of Surface Roughness.

In Fig. 6-8, are shown the diagram of the measured roughness maximum height of the profile R_t and the ten-point average roughness R_z and with the ratio of turning speed versus feed rate (F factor - Table 2), for all the investigated cases.

From the diagrams presented in Fig. 6-8, we observe that some measuring areas seem to deviate from the general rule (mark with cycle). This is due to the fact that during the cutting procedure, an unforeseen factor affected the machining of the metal, affecting its roughness.

This deviate is presented and analyzed in next paragraph.

In order to normalize the diagrams in Fig. 6b, 7b and 8b, we have removed the marked points.

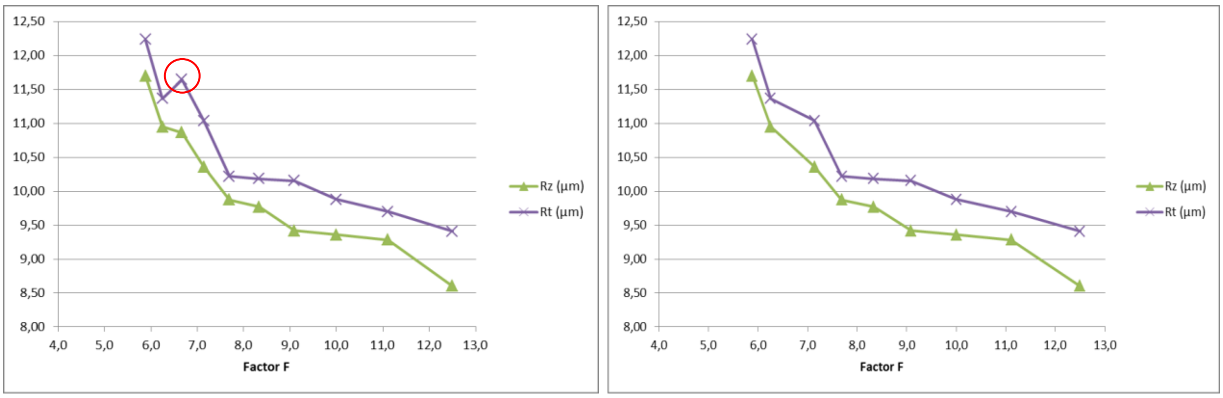
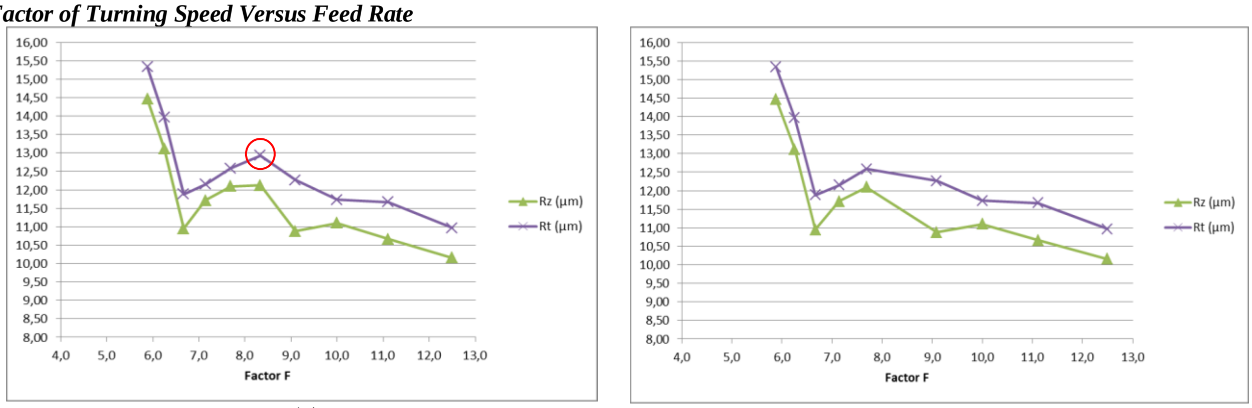


Figure 6: Diagram of Rt and Rz with Factor F for RSt 37-2 Material (a) Not normalized, (b) Normalized.



(a) (b)

Figure 7: Diagram of Rt and Rz with Factor F for UNS C38000 Material (a) not Normalized, (b) Normalized.

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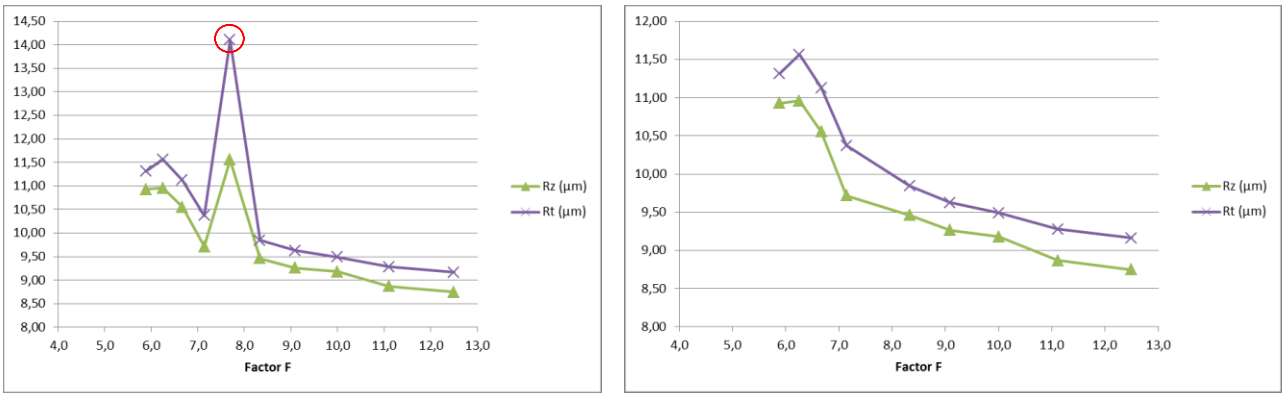


(a) (b)

Figure 8: Diagram of Rt and Rz with Factor F for AISI-SAE 304material (a) not Normalized, (b) Normalized.

In Figure 9-11, the diagram of the roughness absolute average R_a and the root mean square deviation R_q with the ratio of turning speed versus feed rate (F factor - Table 2) and the exponential line, are presented.

As we can see, the higher ratio F gives lower absolute average Ra and root mean square deviation R_q. This means that with a higher ratio F we have better surface quality.

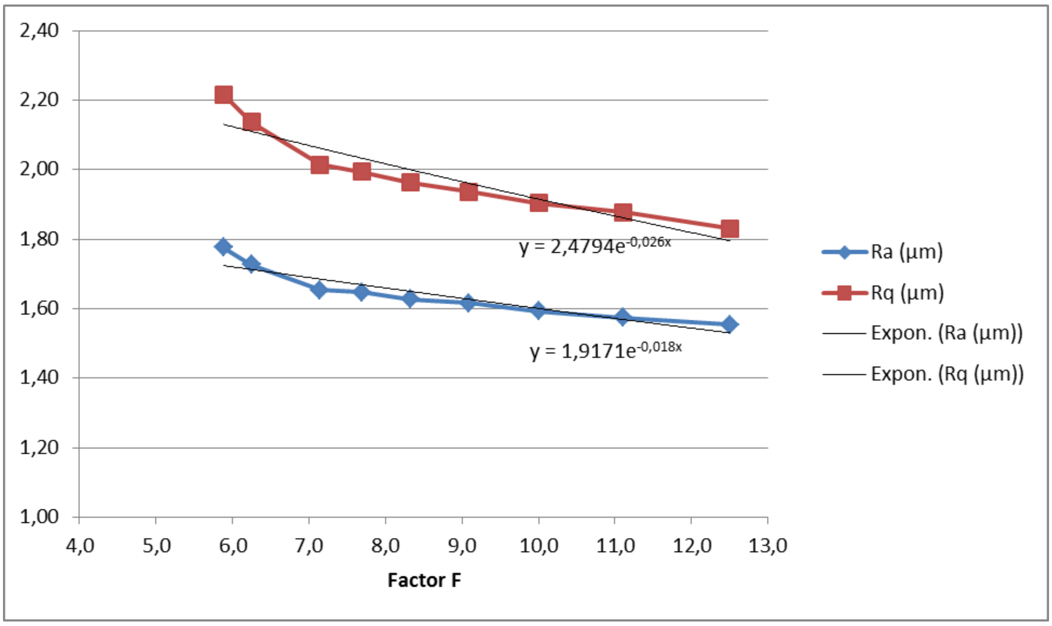


Figure 9: Diagram of Ra and Rq with Factor F for RSt 37-2 Material.

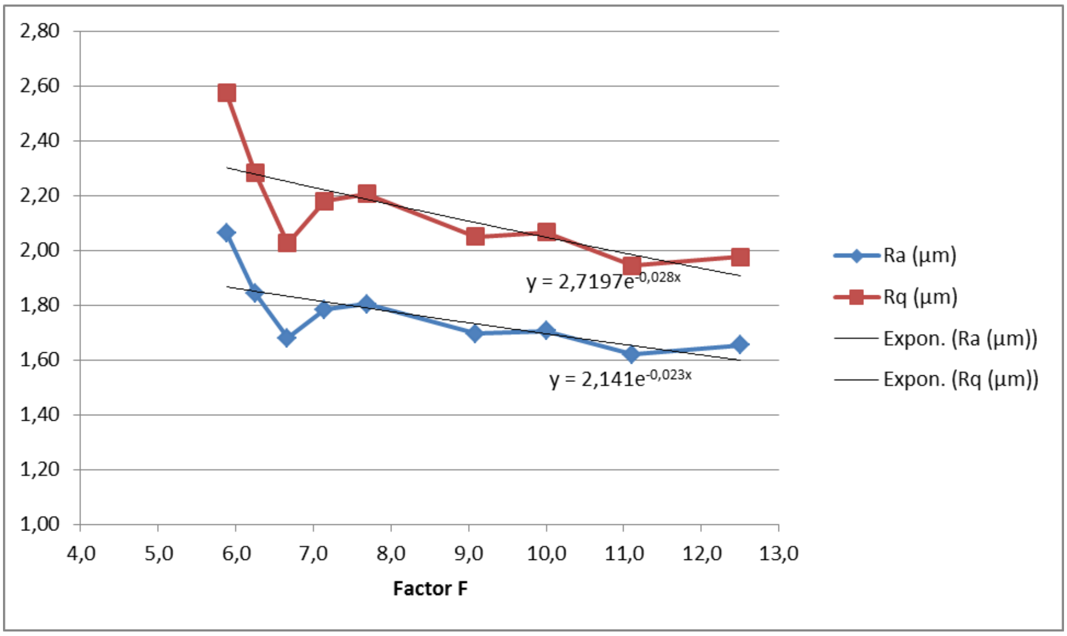


Figure 10: Diagram of Ra and Rq with Factor F for UNS C38000 Material.

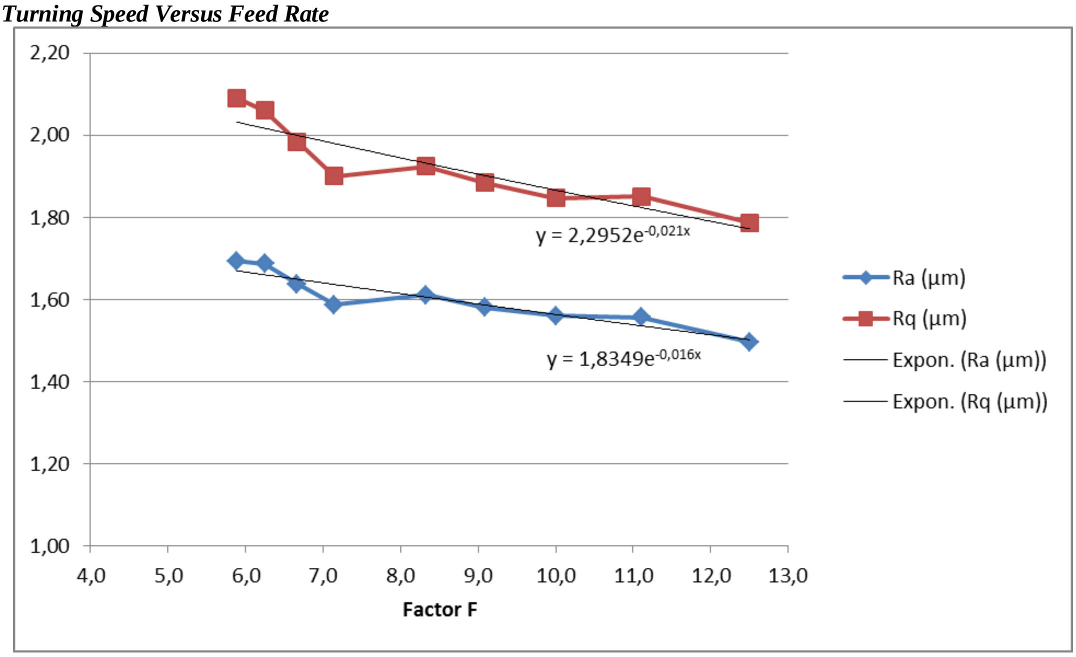


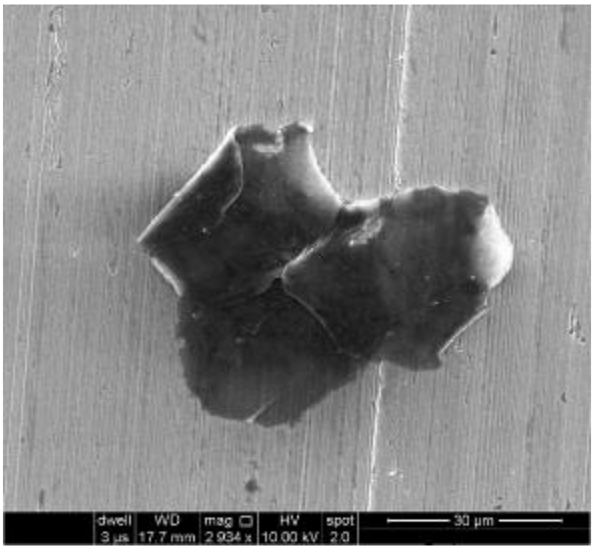
Figure 11: Diagram of Ra and Rq with Factor F for AISI-SAE 304 Material.

As mention above, during the cutting procedure, an unforeseen factor has affected the machining of the metal, with unsmooth results on the roughness of some areas of the surface.

In order to further investigate these unpredictable results, a more extensive research was done in these areas, utilizing Scattering Electron Microscopy, in order to observe the microstructure of the material.

Metallographic observation revealed an alteration of the microstructure of the material due to cutting, in the investigation areas.

The alterations of the material's microstructure are presented in Figure 12-16.



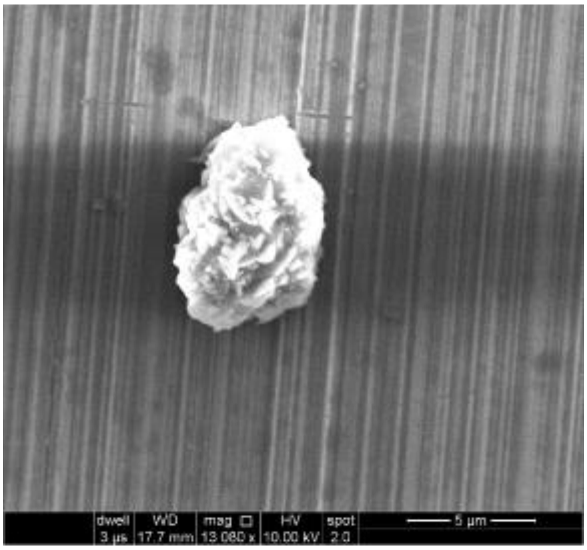


Figure 12: Metal Debris on the Surface of the Material.

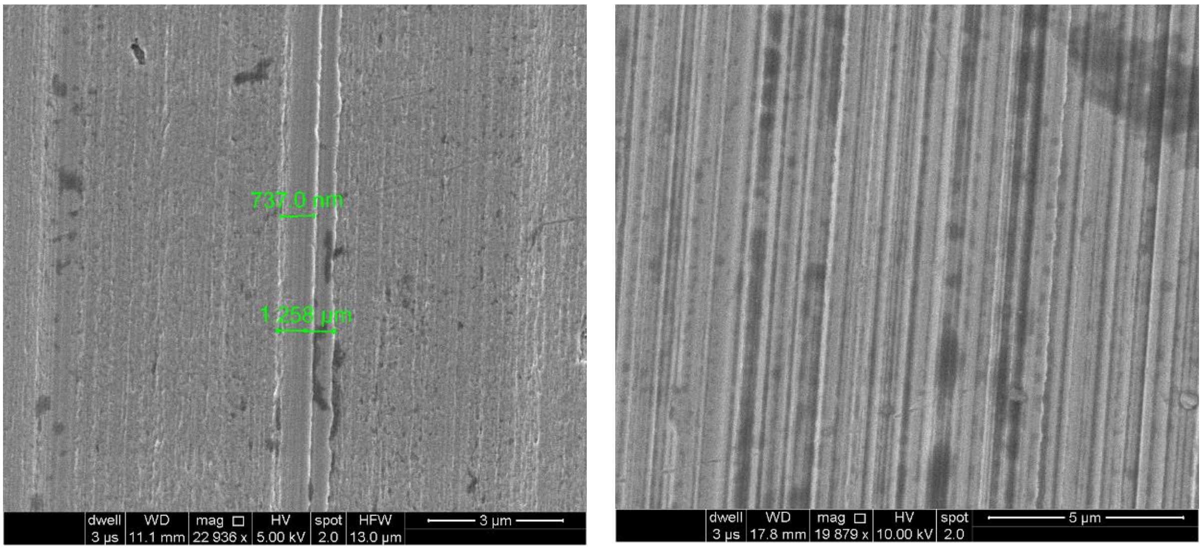


Figure 13: Long Grooves on the Surface of the Material.

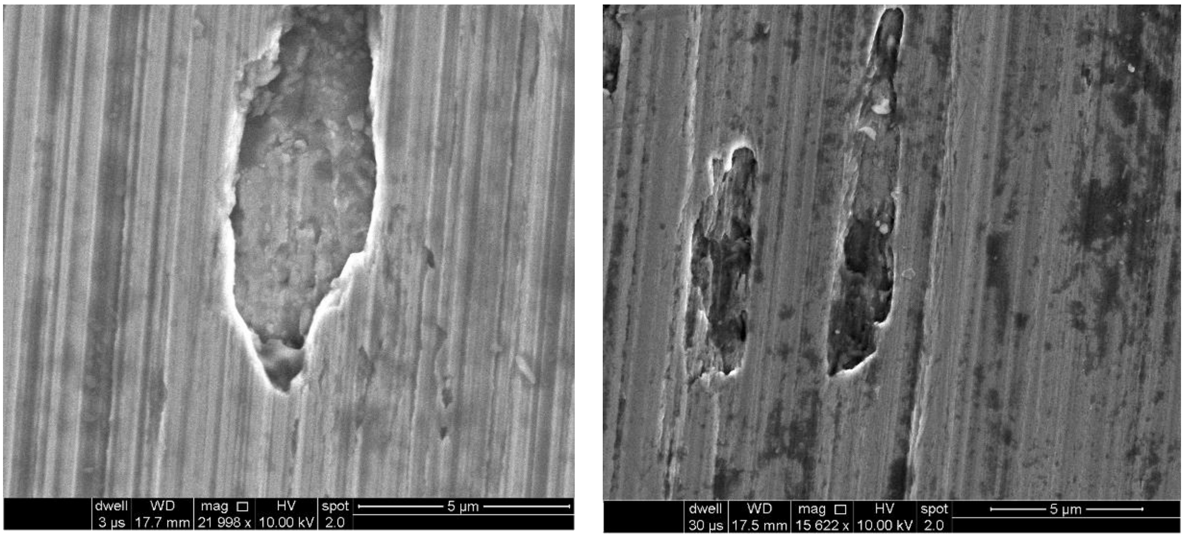


Figure 14: Cavities in Material's Microstructure.

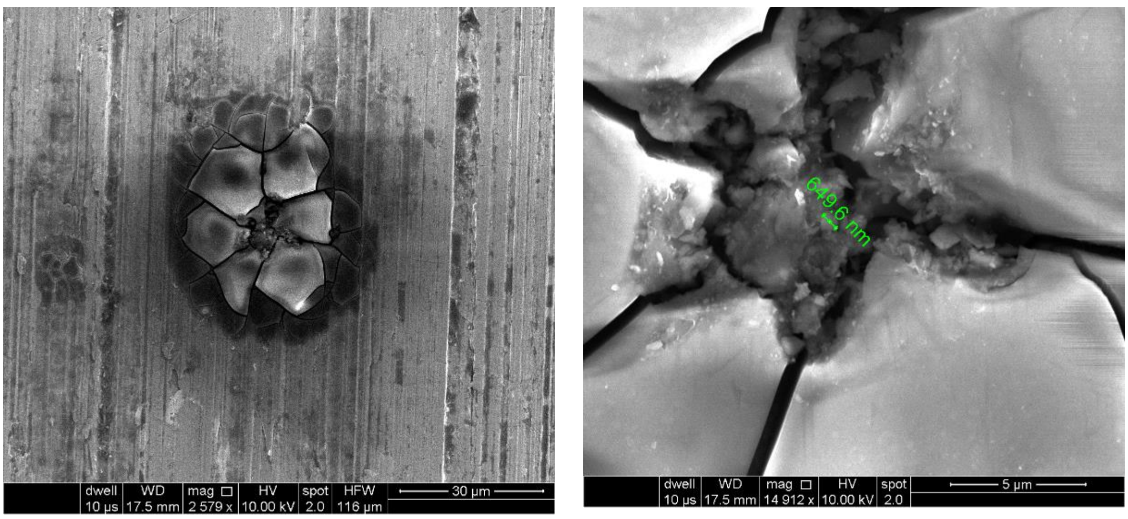


Figure 15: Local Microstructure Failure due to high Temperature Increase.

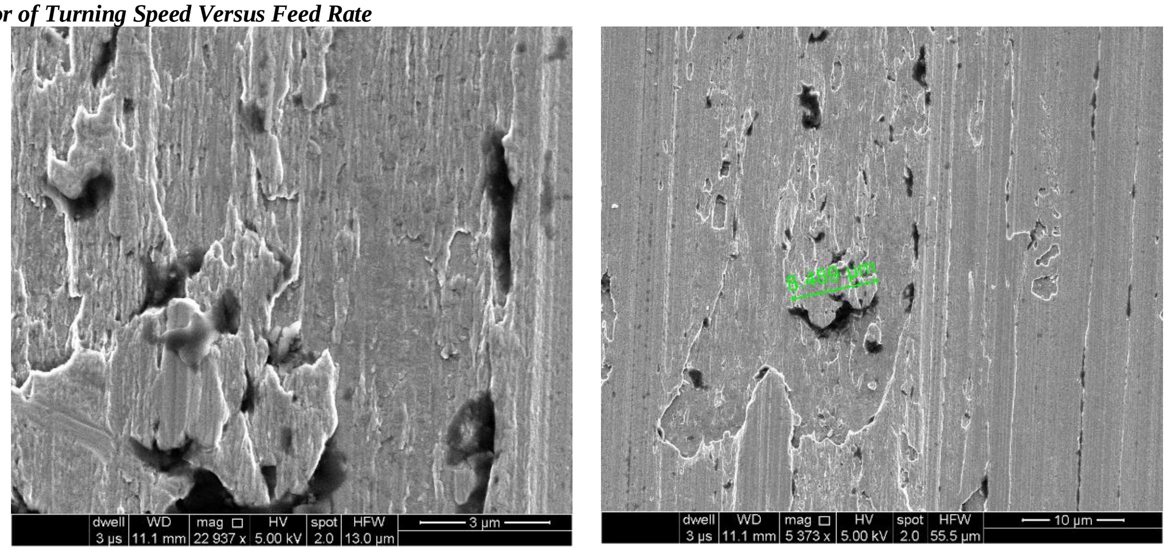


Figure 16: Smeared Material on the Surface of the Material.

In all the examined materials, alterations of the material's microstructure were observed, on different values of ratio F, indicating that depending on the processing material, the combination of turning speed and feed rate can affect the microstructure of the material differently.

Specifically, the SEM microscope observation shows, local microstructure failure due to high temperature increase and Cavities in the material's microstructure for the UNS C38000 (Figure 14, 15). Smeared material and long grooves on the surface for the AISI-SAE 304 (Figure 13, 16). Metal debris on the surface of the material and cavities in the material's microstructure for the RSt 37-2 (Figure 12, 14).

4. CONCLUSIONS

The relationship between turning speed versus feed rate greatly affects the roughness of a material and its microstructure. In the present work, we investigated the effect of the factor concerning the ratio of turning speed versus feed rate, on the material's roughness and alteration of the microstructure. The experiments were performed on three different materials, namely AISI-SAE 304 stainless steel, RSt 37-2 construction steel and UNS C38000 brass. Experimental measurements have been obtained using a profilometer for surface roughness and a SEM for the microstructural observations. It has been demonstrated that within the permissible turning speed limits and feed rate, the ratio as a factor, can positively affect the roughness as it decreases. Specifically, four of the most important magnitudes of material's roughness, the surface roughness absolute average Ra, the maximum height of the profile Rt, the root mean square deviation Rq and the average roughness Rz, can be reduced by increasing the factor of the ratio of turning speed versus feed rate. Additionally, with the optical observation of the material's microstructure using S.E. Microscopy, it was deduced that with the increase of the factor of the ratio of turning speed versus feed rate, the roughness of a material can be improved without altering its microstructure.

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